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Flood Susceptibility Mapping of Makera District and Environs in Kaduna South Local Government Area of Kaduna State-Nigeria

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ABSTRACT

*The increased flood incidences experienced all over the world due to climate change dynamics call for a concerted effort towards forestalling future hazards. This study thus, identified the areas that are susceptibility to floods in parts of the Makera district of the Kaduna South Local Government Area in Nigeria using geospatial techniques. Geographic Information System (GIS) was used to produce thematic layers of the factors contributing to flooding (**e**levation, slope, drainage density, rainfall, land use/land cover); and a multi-criteria evaluation particularly the "Analytical Hierarchical process" (AHP) was applied to determine the locations at risk. The various thematic layers were integrated into the weighted overlay tool in the ArcGIS 10.3 environment to generate the final susceptibility map. The overlay tool was also used to determine the elements at risk of flood in the study area. The results show that the areas that were highly susceptible to flood constituted about 39% of the study area, while moderate and low vulnerable areas constituted about 26% and 35%, respectively. The result of the multi-criteria analysis revealed that land use/land cover (0.601) was the factor that contributed the most to flooding in the study area based on the criteria weights followed by rainfall (0.470), drainage density (0.326), elevation (0.144), and slope (0.099), respectively. The study recommends that authorities concerned should ensure strict adherence to land use planning act, such that floodplains are avoided during development of any type.*

Keywords: Flood, Geospatial technique, Multi-criteria analysis, Susceptibility

1.0. Introduction

The incredible amount of water (as far as waterway or fluvial flow is concerned) is basically brought about by the overwhelming precipitation that overflows into the streams which surpass the limits of the waterways, making water flow out over the land (Oxford Learner's Dictionary, 2020). Poor urban arrangement, urban populace development, poor ecological administration and the indiscriminate disposal of solid waste additionally influence flood occurrence. Flooding is apparently a climate related risk that occurs across the entire globe. It is a phenomenon which happens when flood water spreads or shrouds the land. Flood is one of the common natural risk desolating the scene of humanity throughout the years and at whatever point flood happen, they bring about the loss of properties, lives, destruction of farmlands and so on (Ojeh and Victor, 2014).

Flooding is turning into an increasingly frequent occurrence in Nigeria, most especially in urban areas where the impact can be overwhelming. Somewhere in the range of 2011 and 2012, there were cases of flooding in many parts of the country (Nkeki *et al*., 2013). The floods that inundated most parts of Kogi, Delta, Bayelsa, and Anambara states in 2012 are some typical examples. Territories around the River Niger were totally submerged by floods and in excess of 600,000 occupants were rendered homeless, farmlands and numerous lives lost (Nkeki *et al*., 2013). In the year 2012, Nigeria saw the

most noteworthy flood disaster in 100 years, where more than 10 states of the federation were inundated. This occurrence was anticipated by the Nigerian Meteorological Agency (Okonkwo, 2013). According to specialists, submerge was brought about by abundant precipitation which brought about the over flooding of rivers Niger and Benue and their tributaries, from Taraba to Adamawa right toward the southern states of Nigeria.

At whatever point catastrophes of such incredible extents happen, endeavours are typically made to forestall future events where conceivable, or if nothing else limit the effects through different preventive projects and components (Vallecillo *et al.*, 2020). Ever before now, and in comparable circumstances in Nigeria, manual techniques, for example, land survey, field studies, administration of questionnaires and interviews were the common methods of data acquisition and on which crucial decisions on such matters were made (Ikusemoran, 2000). The vast majority of these methods were found not adequate to give perpetual answers for such issues on the grounds that most on occasion, the disappointments of these choices originate from the issues related with the information on which such choices were based. Thus, there is the requirement for the utilization of computerized innovation, for example, remotely sensed information and Geographic Information System (GIS) methods for information and investigation. Hence, consequent choices that is liberated from human controls and which can be viewed as dependable and exposed to future update are required for flood risk evaluation in Nigeria.

Geospatial techniques have been successfully applied all over the world for flood monitoring, susceptibility, management and control. For instance, Haq *et al.* (2012) applied remote sensing and GIS to monitor and assess damages caused by flood in the Sindh province of Pakistan. MODIS Aqua and Terra images of the study area were acquired during the flood events and used as the main input to assess the damages with the help of GIS analysis tools. Pieter *et al.* (2010) applied GIS for flood risk management in Flanders: a region in Belgium where a risk-based technology was created to quantitatively assess flood risk based on hydrologic models, land use information and socio economic data. The method was said to have been implemented in a specifically designed GIS-based flood risk assessment called LATIS which was assessed to have the capability to perform risk analysis quickly and effectively. Nwilo *et al.* (2012) adopted remote sensing tools and Cellular Automated Evaluation Slope and River (CAESAR) to determine inundation level and assess the susceptibility of settlements in the floodplains of Adamawa State. The results showed that, an average of 134 settlements were prone to hazard. Elsewhere in Papua New Guinea, Samanta *et al*. (2018) investigated the usefulness of remote sensing, GIS and the frequency ratio (FR) for flood susceptibility mapping. Faisal *et al*. (2018) analysed the damages caused by flooding according to the different land uses (urban area or agricultural lands), flood height and thus the percentages of loss in the different land uses in various corresponding years in the Naogaon District, Bangladesh using remote sensing and GIS.

Kaduna remains one of the most populated metropolitan urban communities in Northern Nigeria with an estimated population of more than 6 million, according to the 2006 National population census (ZEMDA, 2020). Significant parts of the city have been hit by flood over the years. At present in Nigeria, flood hazard maps are not generally accessible. Until such data is accessible, an assessment of notable flood records or hydrometric information (accessible from the Environmental Protection Agency or Office of Public Works), and/or undertaking flood chance evaluations and examination can demonstrate regions in danger from both stream and tidal flooding. Using AHP, a multi-criteria approach, this study thus sought to identify flood prone areas and produce flood susceptibility map of Makera district in Kaduna South Local Government Area of Kaduna State.

2.0. Methodology

2.1. Description of study area

The study location covers a land area of about 33.21 km^2 which is located in parts of the Makera district in Kaduna South Local Government Area (LGA) of Kaduna state. It has a population of 402,390 according to the 2006 National population census (ZEMDA, 2020). Kaduna South LGA is

located between latitude 10°25’30"N and 10°34’00"N of the equator and longitude 7°22ˈ30"E and 7°27’30"E of the Greenwich Meridian (Ezeamaka *et al*., 2019). Figure 1 depicts the study area.

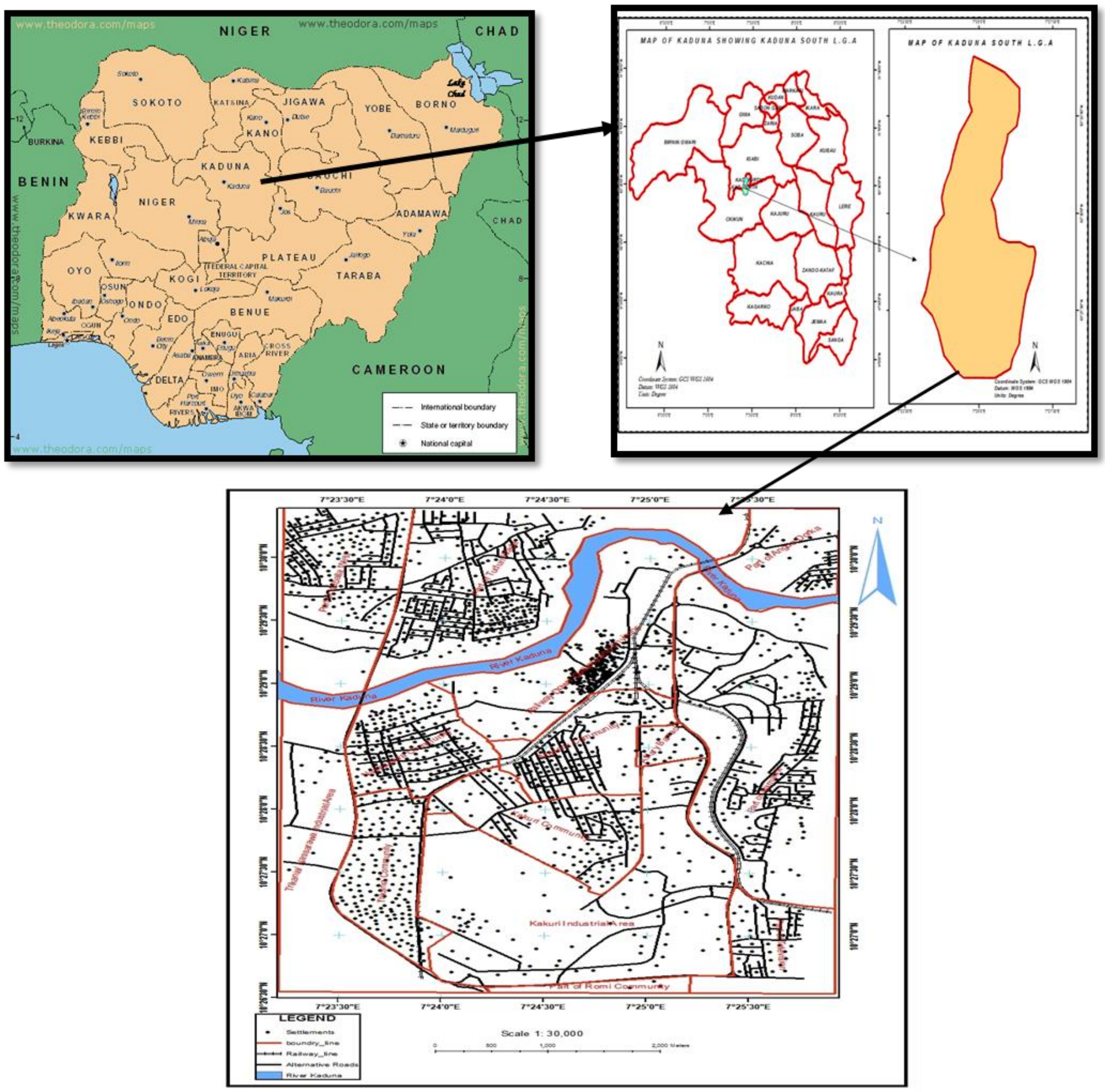

Figure 1: The study area. (Top left: Map of Nigeria; Top right: Maps of Kaduna State Kaduna South LGA; Bottom: Study area)

2.2. Methods

The flood susceptibility mapping of any location involves planning the methods to be used as well as the sequential process to adopt for efficiency and quality service delivery. It also involves the sources of data to be utilized and the factors of flooding to be considered and analysed in the production of a flood susceptibility map. The workflow diagram adopted in this study is shown in Figure 2.

2.3. Data Sources

Table 1 shows the type of data acquired, resolution, sources, date of acquisition as well as the relevance of the entire primary and secondary data used for this study.

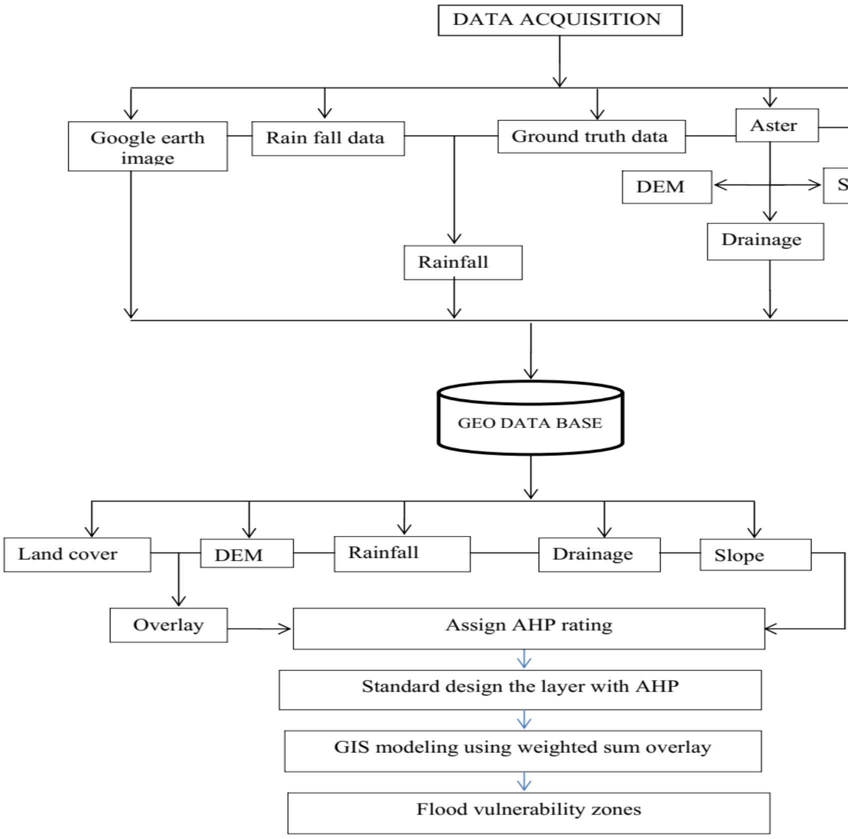

Figure 2: The workflow diagram

Table 1: Datasets and sources

Data Type	Resolution/Scale	Source	Date Acquired	Relevance
ASTER Data	30m	United States Geological Survey (USGS): www.glovis.usgs.gov	2017	Generation of Slope, Elevation and Drainage Density layers
Rainfall Data	36 years (1981-2017)	Nigerian Meteorological Agency (NiMET)	2017	Generation of Rainfall layer
Ground Truth Data	----	Field Survey	December, 2017	Determining the boundary of the communities
Google Image	60m	Google Earth: www.google.com	2017	For processing/digitizing
Landsat 8	30m	United States Geological Survey (USGS): www.glovis.usgs.gov	2017	Land use land cover classification

2.4. Data processing/preparation

The data preparation stage included the enhancement of image, transformation of coordinates, vector data trimming of overshoot/overshoots of lines at intersections, closing gaps in lines and generating polygons, associating attribute data with the spatial feature through the manual input method. Since risk zone assessment of floods largely depends on proximity to water body and the terrain of the area, it was therefore necessary to generate the elevation of the area which was achieved through the DEM creation module of the ArcGIS software, using the Digital Elevation Dataset from ASTER DEM, with 30m resolution, downloaded from the United States Geological Survey (USGS) (www.glovis.usgs.gov), which automatically showed the topography and the heights of each component of the terrain as well as the proximity to the water body. The drainage flow was integrated into the ArcGIS environment to identify areas most likely to be at the risk of flooding (Youssef and Pradhan, 2011). Daily rainfall data of a rain gauge station that lies around the Kaduna Metropolis was acquired from the Nigeria Metrological Agency (NiMET) Abuja. The mean annual rainfall for 36 years was used to create the rainfall map of the study area by interpolation in the ArcGIS environment. The acquired Landsat8 imagery downloaded from USGS (www.glovis.usgs.gov) was

ortho-rectified. Using the supervised classification method, the image was classified using spectral signatures (i.e. reflectance values). This was followed by sub-setting, which involved the process of clipping out the area of interest (AOI) otherwise known as the study area from the image. For ground truthing, coordinates of selected features were acquired using the Garmin 78sc Hand held GPS receiver.

2.5. Deriving criteria weights using analytical hierarchical process (AHP)

The relationship between five layers and their relationship between their various attributes were derived using the Analytical Hierarchical Process (AHP) (Saaty, 1980) approach. The pair-wise comparison matrix was generated with the relative important values determined from the Saaty's 1-9 Scale (see Table 2) where a score of 1 represents equal importance between two attributes, and a score of 9 indicates the extreme importance between one attribute and another (Saaty, 1980).

Table 2: Fundamental scale for pair-wise comparison (Saaty, 1980)

Intensity of Importance*	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favour one element over another
5	Strong importance	Experience and judgment strongly favour one element over another
7	Very strong importance	One element is favoured very strongly over another; its dominance is demonstrated in practice.
9	Extreme importance	The evidence favouring one element over another is of the highest possible order of affirmation.

**2, 4, 6 and 8 are intermediate values*

The AHP captures the idea of uncertainty in judgments through the consistency index and the measure of consistency (Saaty, 2000). Consistency Ratio (CR) is a measure of consistency of judgments amongst the criteria.
(a) The rule of thumb states that the CR should be less than or equal to 0.10;
(b) Thus a value of 0 to 0.10 is accepted in practice;
(c) Any higher value indicates that the judgment warrants a re-visitation;
(d) CR thus is evaluated as $CR = CI/RI$.

CI which is given by $\frac{\lambda_{max}-n}{1-n}$, represents consistency index which reflects the consistency of one's judgment. CI is calculated by averaging the value of the consistency vector (calculated factor weight). RI denotes random inconsistency index that is dependent on the sample size (see Table 3).

Table 3: Random indices (RIs) for N = 1-10 (Saaty (1980))

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.89	1.12	1.24	1.32	1.41	1.45	1.49

3.5. Thematic layer integration

All the weighed data sets were integrated in the ArcGIS 10.3 software to produce the flood susceptibility map by weighted overlay where each class' individual weight was multiplied by the map scores and the results added. This procedure is facilitated by the following equation (Saaty, 1980):

$$S = \sum W_i X_i \tag{1}$$

where;
S -susceptibility
W_i -weight for each map
X_i -individual map

3.0. Results and Discussion

The factors contributing to flooding considered in this study include land use and land cover, drainage density, rainfall, elevation and slope, respectively.

3.1. Land use

Land use affects the surface runoff, evapo-transpiration and rate of infiltration (Yalcin *et al.,* 2011). For the land use classification based on the supervised method, five different classes were considered which include vegetation, built-up, farmland, water body and bare ground (see Figure 3). The land use and land cover classification shows that farmland areas account for 40.11% of the total land coverage while built-up, vegetation, bare ground and water body account for 29.34%, 20.72%, 5.05% and 4.77%, respectively. Table 4 summarizes the land use and land cover class of the study area and the corresponding percentage of each feature.

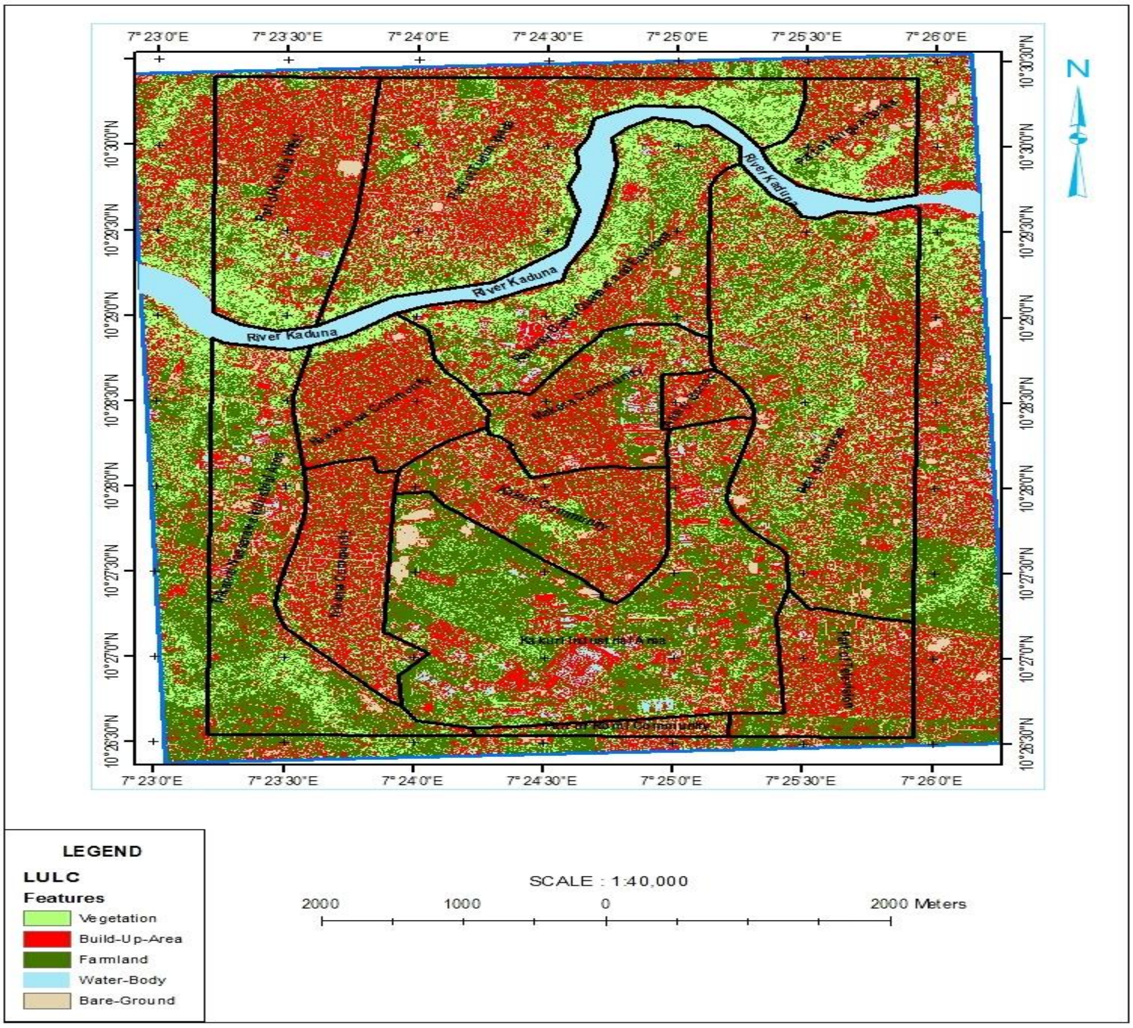

Figure 3: LULC map of the study area.

Table 4: Land use and land cover classes

LULC Feature	Area (ha)	Percentage (%)
Vegetation	662.87	20.72
Built-up	938.48	29.34
Farmland	1282.93	40.11
Water body	152.63	4.77
Bare ground	161.68	5.05
Total	3198.59	100.00

3.2. Land use drainage density

The drainage density of any given area shows how well or poorly a watershed is drained by stream channels. Drainage density has been recognized as significant factor on the formation of flood flows (Gardiner and Gregory, 1982). Thus a high density indicates a greater flood risk, while a low density generally implies decreasing flood volume. The drainage density (see Figure 4) was generated from the DEM. The drainage density was divided into five catchment (0 to 28400 km) areas. Scott *et al*. (2015) observed that the topography of a drainage basin can affect the speed with which the precipitation flows. In other words, the steeper the basin, the more quickly it drains and vice versa.

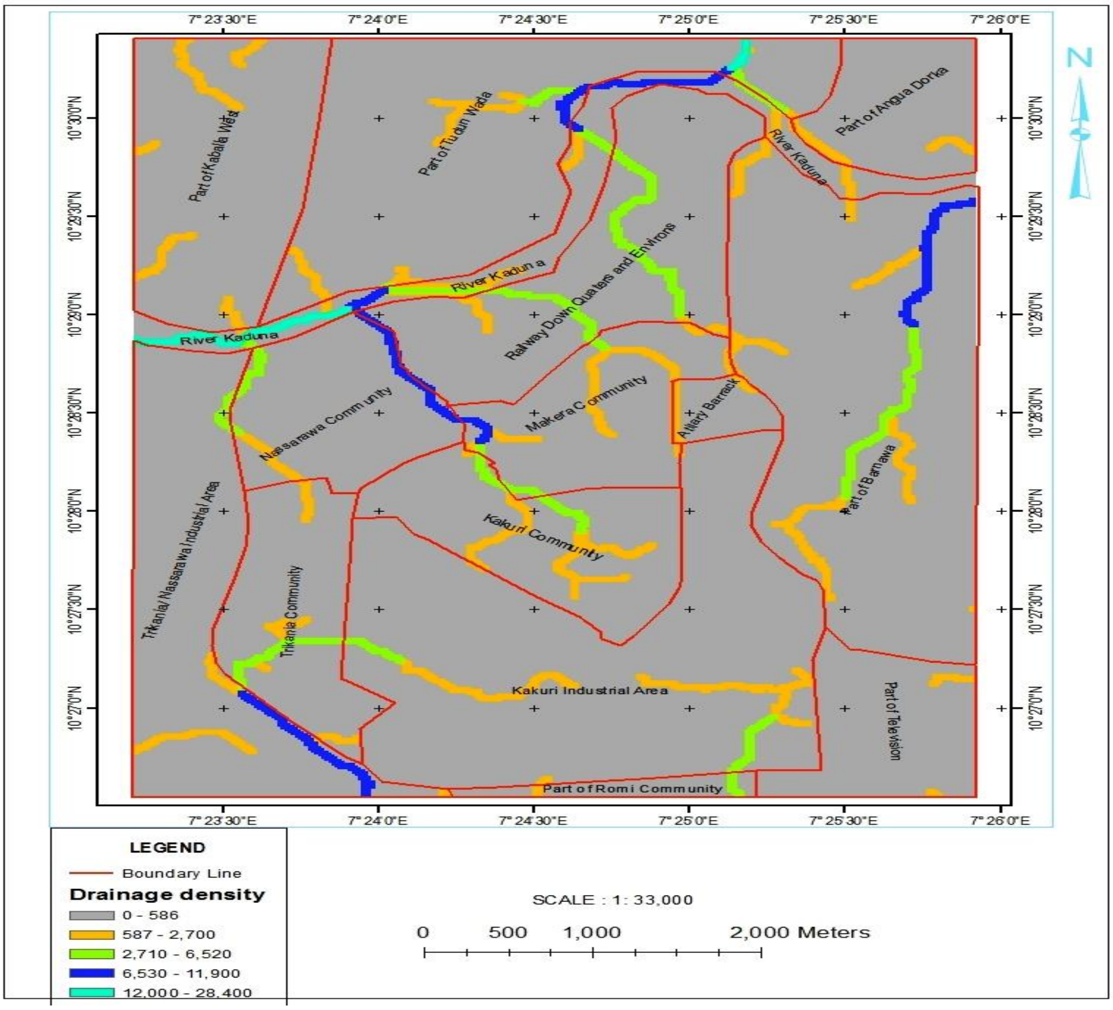

Figure 4: Drainage density based on catchment area

3.3. Rainfall

The rainfall pattern of the study area was generated from the rainfall data obtained from the Nigeria Metrological agency (NiMET) Abuja. The rainfall data (10 stations) for a period of 36 years (1981-2017) was collected and interpolated in the spatial analysis tool of the ArcGIS 10.3 software. The results revealed that the rainfall amount in the study area ranged from 1290 mm to 1178 mm per annum (see Figure 5). Higher rainfall amount might probably mean grater flood risk.

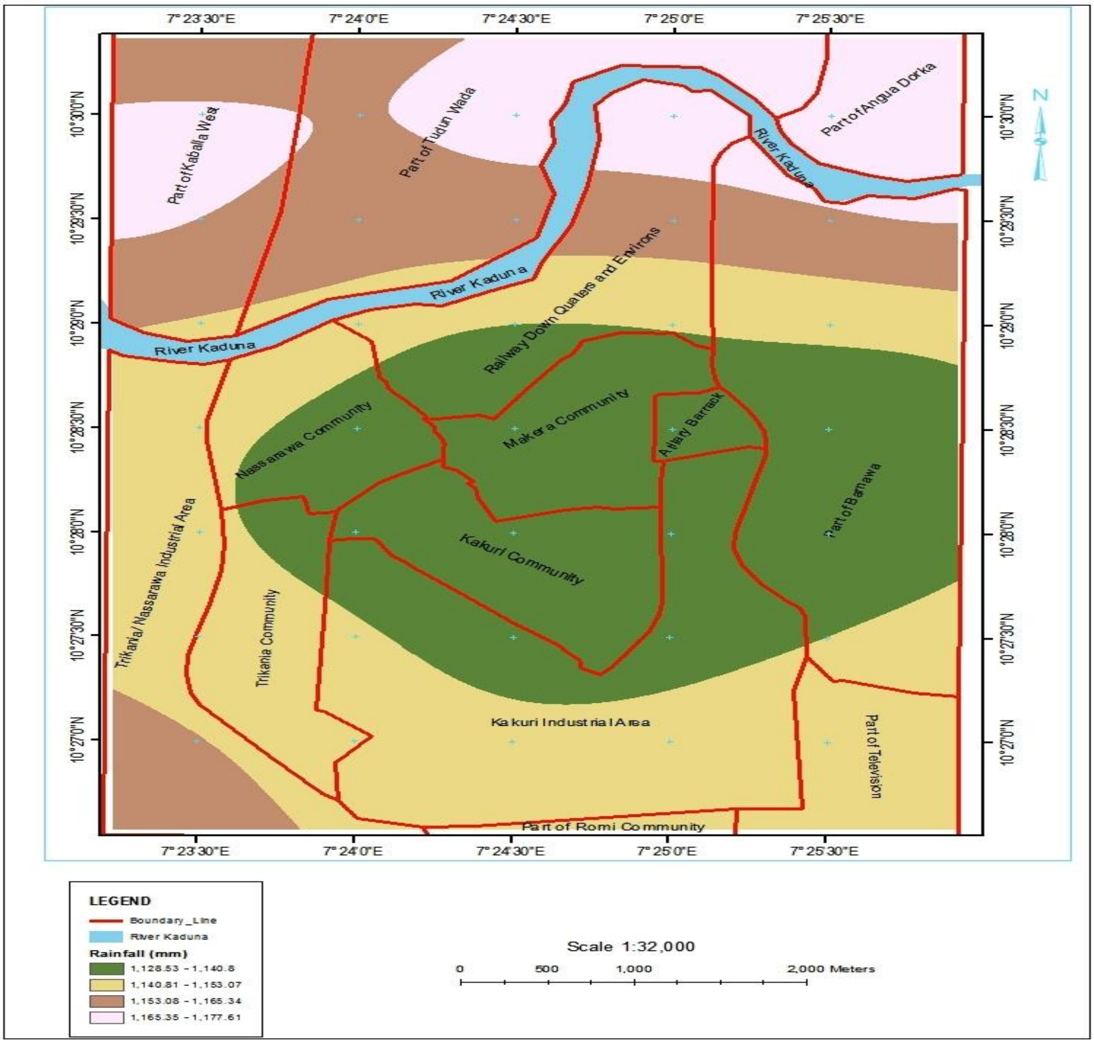

Figure 5: Rainfall pattern of the study area

3.4. Elevation and slope

The elevation dataset was obtained from the ASTER DEM which reveals that the elevation of the study area ranges from 542.20m to 634.70 m (see Figure 6). Figure 7 presents the slope map for the study area. The result obtained shows that the slope of the study area ranges from 0.003 to 25.40 degrees.

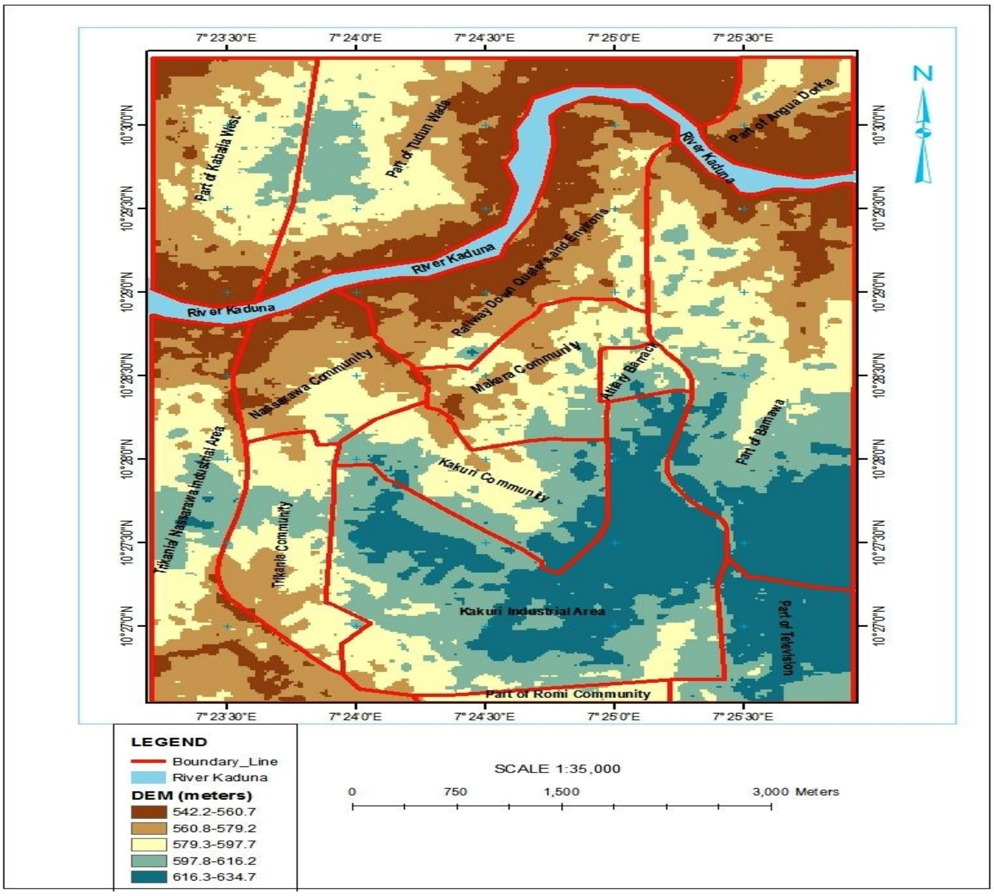

Figure 6: Elevation pattern of the study area

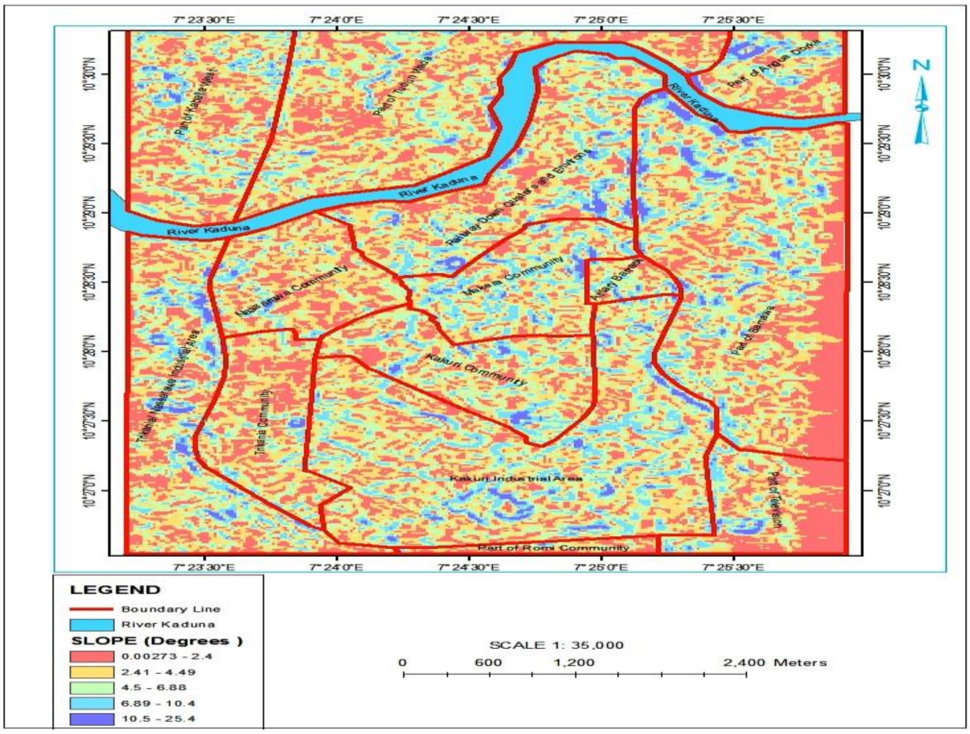

Figure 7: Slope pap of the study area

3.5. Flood susceptibility map

This section presents the result of the pair-wise comparison carried out for the five factors contributing to flooding under consideration in this study and the generated flood susceptibility map.

Table 5 presents the pair-wise comparison matrix for the factors contributing to flooding in the study area.

Table 5: Pair-wise comparison matrix for factors of flooding

Features	Rainfall	DEM	Slope	Drainage	LULC	Weight
Rainfall	1	1/4	1/5	1/7	1/9	0.47
DEM	4	1	5	1/3	1/6	0.14
Slope	5	1/4	1	1/4	1/7	0.09
Drainage	7	3	4	1	1/2	0.33
LULC	9	6	7	2	1	0.60

Consistency Ratio (CR) = 0.06

From the results of the various weights generated it has been revealed that the land use and land cover factor with 0.60 as its weight has the greatest influence on flood occurrence in the study area. This is followed by Rainfall (0.47), Drainage Density (0.33), Elevation (0.14), and Slope (0.09), respectively. The CR value of 0.06 indicates that the weighting of the factors was consistent (i.e. CR < 0.1). Table 6 shows the percentage of the various areas covered by the flood.

Table 6: Area coverage of the flood susceptibility zones

Susceptibility	Area (ha)	Percentage (%)
Very High	423.50	14.90
High	682.09	24.10
Moderate	736.10	25.90
Low	588.90	20.71
Very Low	411.71	14.49
Total	2842.29	

From the flood susceptibility map (see Figure 8), it shows that about 423.50 ha which is about 14.90% of the study area is very highly vulnerable to flood, and these areas include large parts of railway down quarter, Anguwan Dorka, parts of Nassarawa, Kaballa west and Tudunwada. Areas with high flood susceptibility include the southern parts of Trikania, Nassarawa, and some parts of Barnawa covering 682.09 ha which is about 24.10% of the study area. Moderate venerable areas covered large parts of Tudunn Wada, part of Kaballa west, large part of Barnawa, Kakuri community, part of Makera and Romi covering 736.10ha which is about 25.90% of the total project area. Areas with low susceptibility are some parts of Kakuri, Television, and Barnawa covering 588.90 ha which is about 20.71% of the total area. The areas that are not vulnerable are large parts of Kakuri industrial area, Television, and a little part of Barnawa representing 411.71 ha which is about 14.49% of the study area.

4.0. Discussions

The primary purpose of flood mapping is to delineate zones with high susceptibility. Flood modelling approach differs considerably, hence enabling different predictive performance and outputs (Nachappa *et al*., 2020). Das (2020) adopted more than eleven factors (elevation, slope, distance from drainage, drainage density, flow accumulation, topographic wetness index, rainfall, land use, soil texture, topographic ruggedness index and geology, including socio-economic factors) to map flood prone areas in the Western Ghat coastal belt of India. For convenience and data limitation, and based on Ozkan and Tarhan (2016), the present study, adopted only five factors to construct a flood susceptibility map of Makera district and environs in Kaduna South local government area of Kaduna state-Nigeria using AHP.

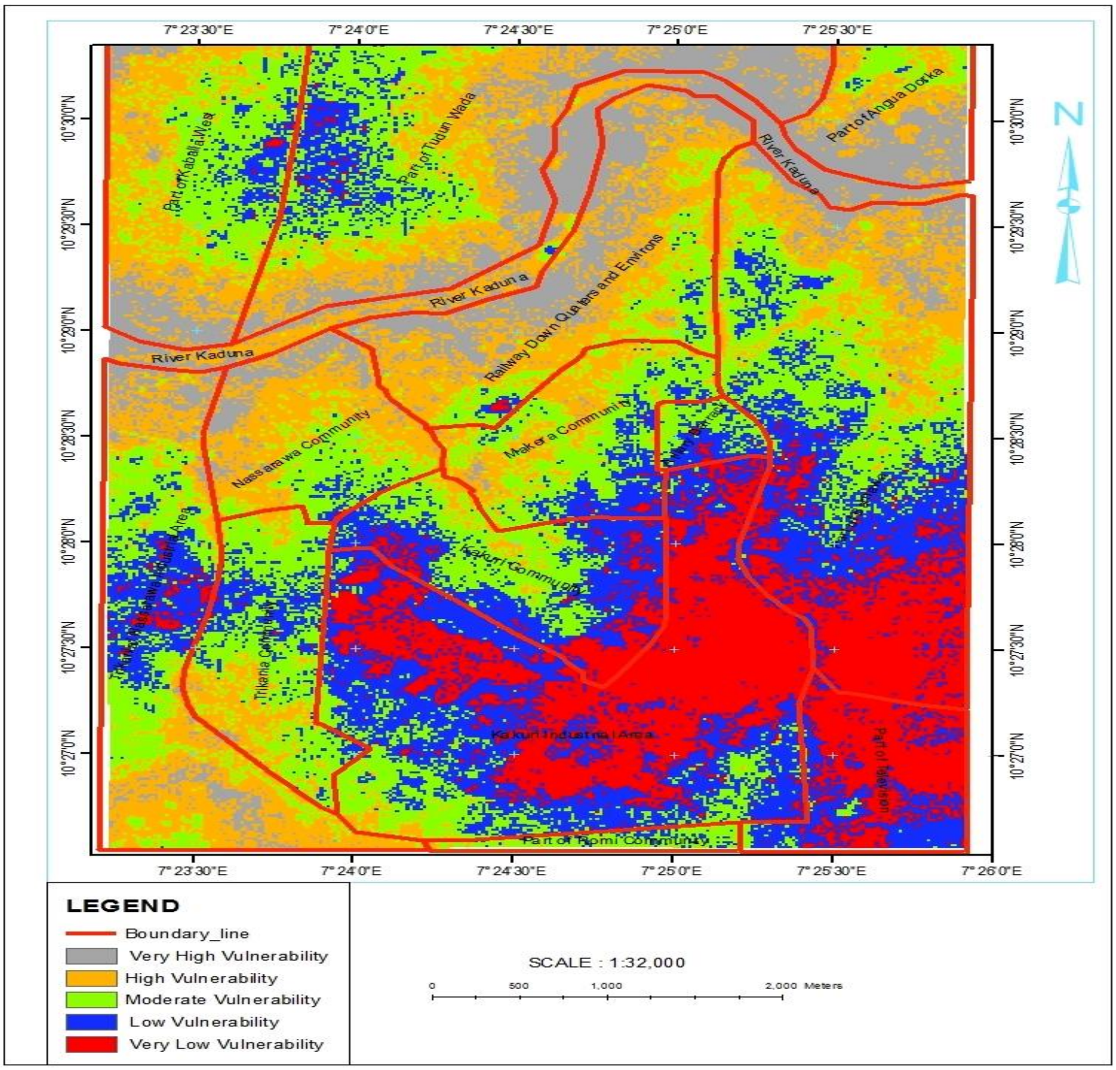

Figure 8: Flood susceptibility map of the study area

The study revealed that the element at risk in the study area shows that farmland accounted for 1282.93 ha (40.11%) which was the major element at risk in the study area followed by built-up area which was about 938.84ha (29.34%) and vegetation accounted for 662.873ha (20.72%). By taking the average of very high and high percentage (see Table 6) of the vulnerable zones, we can conclude that about 19.5% of the study area show high flood risk. The study area is quite populated as a result of urban migration from urban to rural areas in search of greener pastures. Immigrants tend to violate urban building laws and encroach into green areas. Similarly, there are numerous poor drainage system is another factor. Though, the results of this study do not corroborate any study of its kind in the region due to the unavailability of similar studies in the region. It is expected that results can be improved if more risk factors are considered (see for example: Nachappa *et al*., 2020; Das, 2020). Similarly, the accuracy of the result is also affected by the accuracy and sampling error of the DEM (Ozkan and Tarhan, 2016).

5.0. Conclusions

The study assessed the flood vulnerable areas in the Makera district and environs in the Kaduna South Local Government Area of Kaduna State by adopting geospatial techniques and the multi-criteria analysis approach. The study showed that farmlands are most vulnerable to floods in the study area followed by built-up area, and vegetation, respectively. The study also revealed that land use and land cover was the most contributing factor to flood in the study area followed by Rainfall, Drainage Density, Elevation, and Slope, respectively. Thus it can be concluded from this study that although flood is a natural disaster, the activities of man contribute immensely to flood occurrence. These activities include encroachment, violation of building laws, and poor drainage system among others.

The authorities and local community leaders can encourage the improvement of flood hazard information, data collection and prediction capabilities. Land use planning that prevents development on floodplains and allows the areas to be reserved for agricultural or recreational purposes should be improved upon.

For decision support system, numerous studies have utilised slope, LULC, soil type, elevation, rainfall etc. Nevertheless, soil type is one of the most important factors in defining an area's water retention and absorption properties, which influences flood susceptibility. However, due to the unavailability of soil type with acceptable spatial resolution in the study area, the study failed to use soil type as a factor. Not until recently, Nkwunonwo et al. (2020) proposed a soil map for Nigeria from 1985 reconnaissance soil survey. Overtime, due to anthropogenic and non- anthropogenic activities a soil survey of 1985 and completed in 1990 must have change in properties and characteristics. This soil type data to the conception of the current study are biased. On a final note, the study recommends that future studies uses soil type of high spatial and temporal resolution. This can be done by fusion of International Soil Reference and Information Centre (ISRIC) data (https://data.isric.org/geonetwork/) and that of Nkwunonwo et al. (2020).

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